

THE SURROGATE METHOD – CONCEPT

The Surrogate Nuclear Reaction technique can be employed to determine indirectly the cross section for a particular type of ‘desired’ reaction, namely a two-step reaction that proceeds through a “compound nuclear state”. An example is shown in Figure 1. In the first step, a projectile a impinges on a target nucleus A to form an intermediate “compound” nucleus B^* , where the $*$ indicates that the intermediate nucleus is in some excited state. In the second step, the intermediate nucleus decays into the final reaction products c and C . Direct measurements of the reaction $a + A \rightarrow c + C$ are impossible when the target A is very short-lived, or when the reaction is inhibited by a strong Coulomb barrier between a and A . Reliable calculations of the $a + A \rightarrow c + C$ cross section are too difficult when several possible decay channels have to be considered (In particular, fission, which plays an important role in the actinide region, introduces large theoretical uncertainties). However, when the desired reaction proceeds through a compound state, here B^* , it is possible to determine the relevant cross section indirectly by using a combination of nuclear theory and experiment. A compound nucleus is, by definition, a nucleus in an excited equilibrated state. As such, the nucleus has ‘lost all memory of its history’, that is, it is independent of the formation process. In the Surrogate method, the compound nucleus B^* is produced by means of an alternative (“Surrogate”) reaction, here $d + D \rightarrow b + B^*$, where D is a stable target. Intensities, energies, and emission angles of the decay products of B^* into the channels $c + C$ and $a + A$ (and others) are then measured in coincidence with the outgoing particle b from the initial reaction. From these measurements, the probabilities for the decay of B^* into the possible exit channels can be determined. When this information is combined with the calculated cross sections for the formation of the compound nucleus B^* in the desired reaction, the total cross section for the desired reaction ($a + A \rightarrow c + C$) can be inferred.

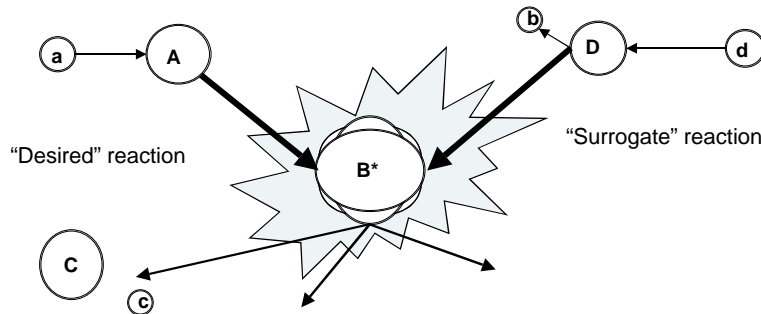


FIG. 1: Schematic representation of the Surrogate reaction mechanism. The Surrogate approach allows one to indirectly determine the cross section for a two-step reaction $a + A \rightarrow B^* \rightarrow c + C$ proceeding through a compound nuclear state B^* . In the Surrogate method, the compound nucleus B^* is produced by means of an alternative (“Surrogate”) reaction, here $d + D \rightarrow b + B^*$, and the reaction cross section is obtained by combining the calculated cross section for the formation of B^* with the measured decay probabilities for this state. The Surrogate technique is particularly valuable when the target of interest, A , is short-lived and a suitable Surrogate reaction involving a stable target D can be identified.

The Surrogate reactions idea was first explored by Cramer and Britt [1] and by Britt and Wilhelmy [2], with the goal to infer (n,f) cross sections from (t,pf) and (^3He ,xf) reactions, respectively. The results from these initial attempts demonstrated the feasibility and value of the Surrogate method, although there were still significant disagreements between the cross sections inferred from these reactions and direct (n,f) data (where data were available). A recent reanalysis by Younes and Britt [3–5] of the (t,pf) reactions incorporated spin and parity dependences and achieved significantly better agreement with the direct measurements. These results illustrate the potential of the Surrogate method as well as the need for further investigations. Similarly, preliminary results from Surrogate measurements in the rare earth region, carried out by L. Bernstein (N Division, LLNL) *et al.* at the LBL 88” cyclotron show encouraging agreement with calculations by R. Hoffman (N Division, LLNL) and, at the same time, illustrate the need for a broader, more rigorous, study of the method [6].

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